Features in Future: 4G Visions From a Technical Perspective

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***Abstract*—Mobile communication is continuously one of the hottest areas that are developing at a booming speed, with advanced techniques emerging in all the fields of mobile and wireless communications. Current times are just the beginning for deploying 3G mobile communication systems, while research on the next generation of mobile communications, 4G wireless and mobile networks begin to pave the way for the future. This paper studies the visions of 4G from a technical perspective. After a brief review on the development history and status of mobile communications and related 4G perspectives, we present an overall 4G feature framework based on the kernel concept of integration, in which two key features (diversity and adaptability) of the three targets (terminals, networks, and applications) are described in detail. The concepts of both external and internal diversity of each target are defined to illustrate the causes and solutions of the adaptability feature. Then, along the entire 4G domain, each feature in the framework is deeply discussed from a technical standpoint, in which promising techniques and possible research issues for sufficient support of adaptability are also proposed. Finally, a short summary on 4G visions is presented as a continuum of features in the development of the mobile communications world.**

I. Introduction

Mobile communications and wireless networks are developing at an astounding speed, with evidences of significant growth in the areas of mobile subscribers and terminals, mobile and wireless access networks, and mobile services and applications. The present time is just right to start the research of 4G mobile communications because of:

- Possibility, according to the historical indication of a generation revolution once a decade, and now we are near the end of 3G standardization phase and the beginning of 3G deployment.
- Necessity: according to 3G goals, 3G is necessary but not sufficient to the mobile communication strategy, in which many problems are only partly solved and there are still many problems left to be solved in the next generation, i.e. 4G.

There is plenty of related research on the next generation mobile communications [1-4], and the 4G topics are becoming hotter and hotter. However, most of the ongoing research can be classified into two different classes:

1) Many of the related 4G research focuses mainly on one specific technical area, such as distributed computing, mobile agents, multimedia services, or radio air interfaces, etc.

2) Some pieces of research are interested mainly in 4G scenarios from the standpoints of service provider or user, or a market analyst, from a less or non-technical viewpoint.

The difference of this paper to other related pieces of research is that we are going to present overall visions on the features of 4G mobile communications, based on a feature framework and provide detailed proposals to respective support techniques and research topics.

This paper is organized as follows. Chapter 2 provides a brief review of the development history and status of mobile communications, together with an analysis of the problems of 3G and developing trends summarized. In Chapter 3, after a survey of related 4G perspectives, we present an overall 4G feature framework based on the key concept of integration, and then describe each of the two features (diversity and adaptability) of the three relevant targets (terminals, networks, and applications) in detail. Chapter 4 deeply discusses the adaptability feature of each three targets in the entire 4G domain from a technical standpoint, in which promising techniques and possible research issues are proposed. Chapter 5 figures out a short summary on 4G visions. Chapter 6 concludes the paper.

II. Mobile Communications Review

The history and status of mobile communications are shortly listed in the following, together with the respective evaluations on the chief contributions.

1) Traditionally, wireless systems were considered as an auxiliary approach that was used in regions where it was difficult to build a connection by wireline.

2) 1G was based on analogy technique and deployed in the 1980s. It built the basic structure of mobile communications and solved many fundamental problems, e.g. cellular architecture adopting, multiplexing frequency band, roaming across domain, non-interrupted communication in mobile circumstances, etc. Speech chat was the only service of 1G.

3) 2G was based on digital signal processing techniques and regarded as a revolution from analogy to digital technology, which has gained tremendous success during 1990s with GSM as the representative. The utilization of SIM (Subscriber Identity Module) cards and support capabilities for a large number of users were 2G's main contributions

4) 2.5G extended the 2G with data service and packet switching methods, and it was regarded as 3G services for 2G networks. Under the same networks with 2G, 2.5G brought the Internet into mobile personal communications. This was a revolutionary concept leading to hybrid communications.

5) 3G is deploying a new system with new services instead

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of only providing higher data rate and broader bandwidth. Based on intelligent DSP techniques, various multimedia data communications services are transmitted by convergent 3G networks.

3G still leaves some unsolved problems that it does not concern or concerns only partly. The limitations and difficulties of 3G include:

- Difficulty in continuously increasing bandwidth and high data rate to meet multimedia services requirements, together with the coexistence of different services needing different QoS and bandwidth.
- Limitation of spectrum and its allocation.
- Difficult to roam across distinct service environment in different frequency bands.
- Lack of end-to-end seamless transport mechanism spanning a mobile sub-network and a fixed one.

The development trends of mobile communications can be summarized by the improvement of three aspects, including network area, e.g. data rate, bandwidth, and network capacity; mobility field, e.g. mobile spatial range, speed, coverage ability; and service property, e.g. services quantity, quality, cost, and category.

Table 1 summarizes the entire development of mobile communications with the properties of each generation including starting time, driven technique, representative standard, radio frequency, bandwidth, multi-address technique, cellular coverage, core networks, and service type. Note that it is a misunderstanding that either radio air interface or bandwidth is the criteria for the identification of different generations. Even they cannot be the representative characteristics for the representative generation.

III. 4G FEATURES

A. 4G Perspectives Review

Different 4G feature frameworks have been defined from the standpoints of service subscriber, service provider, researcher and engineer. In the following we give some representatives of 4G perspectives.

1) It is easy to say, based on the developing trends of mobile communication, that 4G will have broader bandwidth, higher data rate, smoother and quicker handoff, wider mobile area, more various service, lower cost, etc. Obviously these ideas do not make too much sense as such.

2) Other than the words “more”, “any” and/or “all” are preferred over expressions used by some others, e.g. anyone can communicate with anyone else, anywhere and anytime, or enjoy any service of any network operator, through any network of any network service provider. These sentences are truly attractive from a subscriber’s viewpoint, and they sound quite like advertisements or word games.

3) DoCoMo introduced the concept of MAGIC for the vision of 4G [5]: Mobile multimedia; Anytime, anywhere, anyone; Global mobility support; Integrated wireless solution; and Customized personal service, which mostly focused on public systems and treat 4G as the extension of 3G cellular service.

4) European Commission (EC) presented a perspective focusing on ensuring seamless service provisioning across a multitude of wireless systems and networks, and providing for optimum delivery via the most efficient network available. Further discussion did continuous promotion around 4G concepts [6-8], e.g. private systems and ad-hoc networks, optimal resource utilization, multiple radio interfaces, WLAN use, standards for interoperability, etc.

5) A broader, all-encompassing perspective of 4G was proposed in [4], according to which 4G will encompass all systems from public to private, operator-driven to ad-hoc, broadband to personal area and ad hoc networks, 2G systems to 3G systems. It focused mainly on personalized services.

TABLE 1 MOBILE COMMUNICATION HISTORY AND STATUS

Property	1G	2G	2.5G	3G
Starting Time	1985	1992	1995	2002
Driven Technique	Analogue signal processing	Digital signal processing	Packet switching	Intelligent signal processing
Representative Standard	AMPS, TACS, NMT	GSM, TDMA	GPRS, I-Mode, HSCSD, EDGE	IMT-2000 (UMTS, WCDMA, CDMA2000)
Radio Frequency (HZ)	400M-800M	800M-900M, 1800M-1900M		2G
Bandwidth (bps)	2.4K-30K	9.6K-14.4K	171K-384K	2M-5M
Multi-address Technique	FDMA	TDMA, CDMA		CDMA
Cellular Coverage	Large area	Medium area		Small area
Core Networks	Telecom networks	Telecom networks		Telecom networks, Some IP networks
Service Type	Voice Mono-service Person-to-person	Voice, SMS Mono-media Person-to-person	Data service	Voice, Data Some Multimedia Person-to-machine

It is amusing to see that it is quite easy for anyone to give a prediction on some 4G characteristics, whereas it is more difficult to provide an exhaustive description and sufficient investigations, especially on the support of advanced techniques.

B. 4G Feature Framework

We summarize our proposal of 4G features with one sentence, or even more simply, with one word: integration, i.e. seamless integration of terminals, networks, and applications (together with users). A more detailed analysis and explanation of the definition is as follows.

1) The discussion domain includes three relevant targets, i.e. terminals, networks, and applications. Out of the 4G domain, the user is the only target.

2) The kernel word of the definition is so-called integration, which means the convergence of first the three different targets; second the various modes of each target, which lead to the feature of diversity.

3) The modifier "seamless", which means the character and requirement of integration, implies the support of the adaptability feature between the three targets, each one of which is largely miscellaneous.

The 4G vision framework presented by us is illustrated in Fig.1. Note that networks are transparent to the user. In order to clarify the concept, we define two kinds of diversity: external diversity and internal diversity.

- External diversity is outside the target, which brings along the demand of the adaptability feature to all targets.
- Internal diversity is inside each of the targets, and it acts as the solution for adaptability requirements.

In short, the need for adaptability is caused by external diversity, and it is solved by internal diversity. Here both the external and internal diversity of users are the cause of all adaptability requirements, which implies that the user is out of the technical domain of 4G visions. The two main features, i.e. diversity and adaptability of the three targets – terminal, network, and application – are described in detail in the next section.

C. 4G Feature Description

1) User Diversity: The external diversity of users, i.e. people in different situations, includes e.g. culture, educational background, economic capability, physical property, personal preference, etc. The internal diversity of users, i.e. people with different interfaces, include e.g. vision, hearing, speech, touch sense, hands and fingers, body, etc.

Note that as for users, both their external and internal diversity are to be adapted by the other two targets: terminal and application. Moreover, for adapting the two kinds of user diversity, both the external and internal diversity of terminals and applications are the solution.

2) Terminal Diversity and Adaptability: The terminals' external diversities are the differences of terminals in both

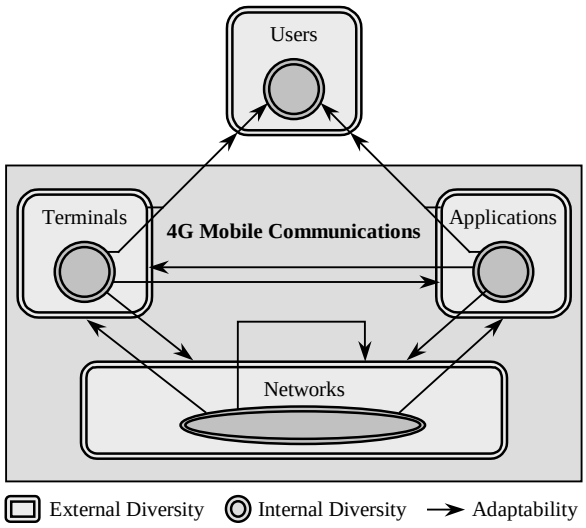

Fig. 1. 4G feature framework

static and mobile attributes. Static attributes include e.g. functionality, weight, size, battery life, human interface, antenna, processing capability, security, style, and cost. Mobile attributes include dynamic attributes of both temporal and spatial features. The former category contains e.g. moving speed and acceleration, along with stationary, pedestrian or vehicular qualities, while the latter is connected to spatial range, e.g. indoors, on-campus, in urban and rural environments, and also direction. The internal diversity of terminals means that one terminal may integrate multiple functions, modes, interfaces, flexibilities, etc.

There are three targets for terminal adaptability. For users, it includes the provision of different terminals to satisfy different users and an individual user's various requirements. As for applications, we hope that miscellaneous services can be delivered to one single terminal. When networks are concerned, a single terminal can reach a wide range of networks despite of location and mobile rate.

3) Network Diversity and Adaptability: The external diversity of networks is obvious. Internet is assorted by nature, while wireless networks keep the same property. For instance air interfaces can integrate all kinds of standards and work on different frequencies. Moreover, multiple operators deploy networks with multiple standards and protocols. The internal diversity of networks means that one network can interconnect with other different networks and transfer various kinds of loads, e.g. cellular systems with various coverage.

Three targets are related to network adaptability. In reference to terminals, network adaptability aims to make multiform mobile devices with a wide range of moving speeds and mobile areas connectable to wireless networks. For applications, there is a requirement that any type and/or quality of service can be delivered through diverse fixed and mobile networks in the most suitable and efficient way. The target for networks themselves is to make it easy to build a

new network or remove an old one, and to make interoperability with one's neighbours seamless despite its heterogeneous nature.

4) Application Diversity and Adaptability: The external diversity of applications will be a reasonable property, and this need not mean that 4G services and applications must be multifarious, in all the aspects of quantity, quality, and type. With internal diversity we mean that one application can be tailored into e.g. multiple levels of quality, various styles, and different kinds of release shape, etc.

Application adaptability is a main feature of 4G services. To users, this means that services can be delivered automatically according to personal preferences of different users. In view of terminals, we hope that various terminals are able to run one application with different formats, such as e-mail in text message, voice, image, or even video. In connection with networks, applications can be transformed into various forms and levels in order to be transmitted correctly and efficiently.

We present the support techniques for each of the above features in the next chapter.

IV. 4G Technical Perspective

It is obvious that 4G, just like all the previous generations, is driven not only by technology, but also by market requirements. This section mainly discusses, from a more technical perspective, possible topics for research and promising techniques of 4G, and focuses mainly on those techniques that give support to the main feature of adaptability by internal diversity of targets in the 4G domain. Fig. 2 gives an illustration of the discussion domain of 4G. Technical details are ignored here because of the length limitation of the paper.

A. Terminals

In order to adapt to the diverse applications and networks, together with the various requirements of users, the terminal domain must possess both internal and external diversity. Support techniques of the field may include the following:

1) User interfaces of terminals vary from traditional keyboard, display, and tablet, to new interfaces based on speech, touch, vision, soft buttons, etc. This will be common at a time when one terminal has multiple user interfaces.

2) Adaptive techniques such as smart antennas, software radio, and smart transceivers, enhance interoperability through simultaneous support of several radio interfaces in a single terminal. This makes a terminal roamable across any air interface standard and connectable to any wireless access point by exchanging configuration software. These approaches can also be used on wireless access points as an advanced smart base station.

3) Terminals will be aware of location and context, often based on some wireless low power sensors that are human-sensitive and/or environment-sensitive in order to monitor and interact with the physical world to report the human and/or environmental factors. The advances in this area have been used in e.g. wearable computers as a novel terminal type.

4) An intelligent terminal is able to dynamically improve its processing capability in order to contain various services. Some function modules can even be downloaded to a terminal when needed.

B. Networks

More advances in networks are needed to keep pace with the rapidly changing terminals and applications, as follows:

1) Smart antenna, software radio, together with advanced base station are the key techniques to achieve adaptability of wireless access points to diverse terminals, i.e. to make radio systems and air networks re-configurable.

2) Hierarchical and ubiquitous as well as overlay cellular systems, including picocell, microcell, macrocell, and magecell ones, implement seamless network interconnection of both symmetric and asymmetric nature, and seamless terminal handoff of both horizontal and vertical levels respectively.

3) Network layer hierarchical mobility management based on Mobile IPv6 and Cellular IP brings quick and seamless handoff to terminals. The Mobile IPv6 also presents a great contribution to the adaptability of heterogeneous networks.

4) Ad hoc wireless networks are a kind of self-deployed wireless networks to make networks portable and adaptable, and thus dynamically share unlicensed radio spectrum.

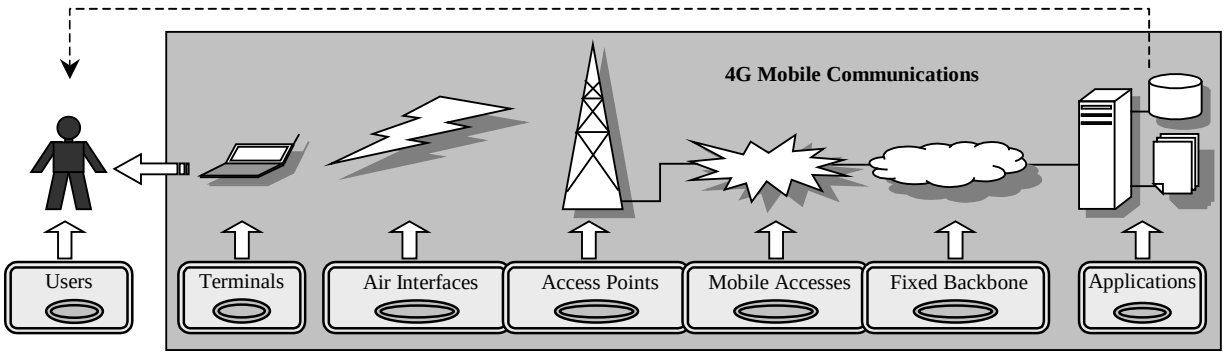

Fig. 2. 4G visions in domains

5) Network reconfiguration can be obtained by the reconfiguration of protocol stacks and programmability of network nodes. Thus, it can adapt dynamically to the changing channel conditions and low or high data rate users.

6) Miscellaneous services can be delivered through a mixture of transmission networks including unicast, multicast, and broadcast ones. According to the service types, e.g. real-time attribute, importance, bandwidth demand, or data stream type, multiple levels of QoS can be defined for various services.

7) Network resource can be dynamically allocated to cope with varying traffic load, channel condition, and service environment. Traffic conditions will be dynamically monitored and controlled via techniques such as distributed and decentralized control of network functionalities.

C. Applications

Adaptability will be one of the basic requirements to the development and delivery of new mobile services. Promising techniques and possible topics may include:

1) Mobile application should refer to a user's profile so that it can be delivered in a way most preferred by the subscriber, such as context-based personalized services. This also brings the applications with adaptability to terminals that are moving in varying locations and speeds. Micro-sensors and GPS receivers are the main driven techniques.

2) Techniques such as adaptive multimedia and unified messaging take the terminal characteristics into account and ensure that the service can be received and run on a terminal with the most suitable form to the host type.

3) Intelligent mobile software agent is a common technique to all of the three targets, which act as a platform for service development, delivery, and auto-configuration.

4) Applications can negotiate with networks so that they can be transferred with the most efficient channel, e.g. indoor networks or WLAN or cellular systems in a wide area. Services will be tailorable in order to fit the different network environments and the varying traffic conditions.

TABLE 2 4G VISIONS SUMMARY

Property	4G
Starting Time	2010-2012
Driven Technique	Intelligent software Auto configuration
Representative Standard	OFDM, UWB
Radio Frequency (HZ)	3G-5G
Bandwidth (bps)	10M-20M
Multi-address Technique	FDMA, TDMA, CDMA
Cellular coverage	Mini area
Core networks	All-IP networks
Service type	Multimedia Machine-to-machine

5) Services and applications can also be smoothly delivered across a multiple domain of operators and service providers.

V. 4G VISIONS SUMMARY

We present Table 2 as a summary of the discussion above, which is a continuum of Table 1 with visions of 4G features.

VI. CONCLUSION

This paper presents 4G visions from a technical perspective. After a brief review of the history and status of mobile communications, we propose a 4G feature framework, in which features of 4G mobile communications are defined. The framework is based on the key concept of integration, and it has the following characteristics:

1) Targets in the framework include users, terminals, networks, and applications, which compass the entire technical domain and operating environment of 4G.

2) Core features of 4G are described as diversity and adaptability of the targets, leading to seamless integration.

3) The feature of diversity includes both external and internal diversity, in which adaptability is caused by external diversity and is solved by internal diversity.

Technical perspectives are presented for each of the features in the paper, in which also some promising techniques and possible research issues of 4G are introduced. The proposed framework provides a layout view on future communication systems, and challenging research topics are figured for guiding systematic research of 4G.

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